Trigger/DAQ

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DOE OHEP Comparative Laboratory Review of Generic R&D

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BROOKHAVEN NATIONAL LABORATORY

a passion for discovery

Office of Science
U.S. DEPARTMENT OF ENERGY

Outline

- ***Introduction***
- ***R&D in High-Throughput Trigger & Data Acquisition***
  - **Component Evaluation & Qualification**
  - **Front-End Systems**
  - **Front-End Data Transfer**
  - **Trigger Electronics**
- ***Connections with Universities & Industry***
- ***Resources & Budget***
- ***Conclusions***

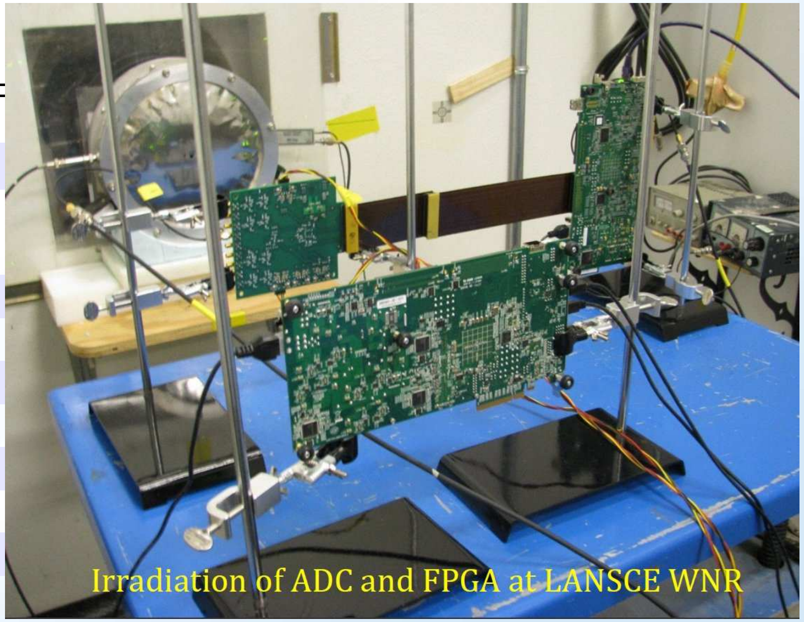
Trigger & Data Acquisition Systems

- ***BNL focuses on generic R&D to optimize the sequence of detector readout, event selection, and data acquisition***
  - driven by our physics interests and experience
  - keeps pace with high-throughput needs of upgraded and future accelerator-based experiments in the Energy and Intensity Frontiers
  - explore COTS solutions while investing in ASIC development
    - *electronics tailored for harsh environments (e.g., cryogenic temperatures, radiation)*
    - *leverage expertise within Physics Department and Instrumentation Division*
  - factorize electronics by function to produce generic answers to interesting problems

Component Evaluation & Qualification

- ***Initiated a program to systematically explore the impact of radiation on performance of COTS components***
  - *close collaboration with university and industry partners*
  - on-going studies: ADCs & FPGAs
  - next steps: DC–DC converters, nuclear interactions on Si to improve GEANT4
  - commissioned 14 MeV neutron source @ BNL for initial component screening
  - further tests at other facilities

Radiation Type	**Facility**
^{60}Co gamma	SSIF at BNL
^{60}Co gamma	ENEA Calliope in Italy
neutrons (1 MeV equiv.)	Fast Neutron Irradiator (FNI) at U. Mass. Lowell
neutrons (∼0.4–600 MeV)	LANSCE WNR at LANL
neutrons (200 MeV)	Svedberg Laboratory (TSL) in Sweden
protons (220 MeV)	CDH Proton Center in Illinois
hadrons	H4IRRAD at CERN
protons (180 MeV)	Svedberg Laboratory (TSL) in Sweden
protons (200 MeV)	Mass. General Hospital Cyclotron
protons (200 MeV)	Indiana University Cyclotron Facility
heavy ions (Ni, Xe, Ar)	Texas A&M

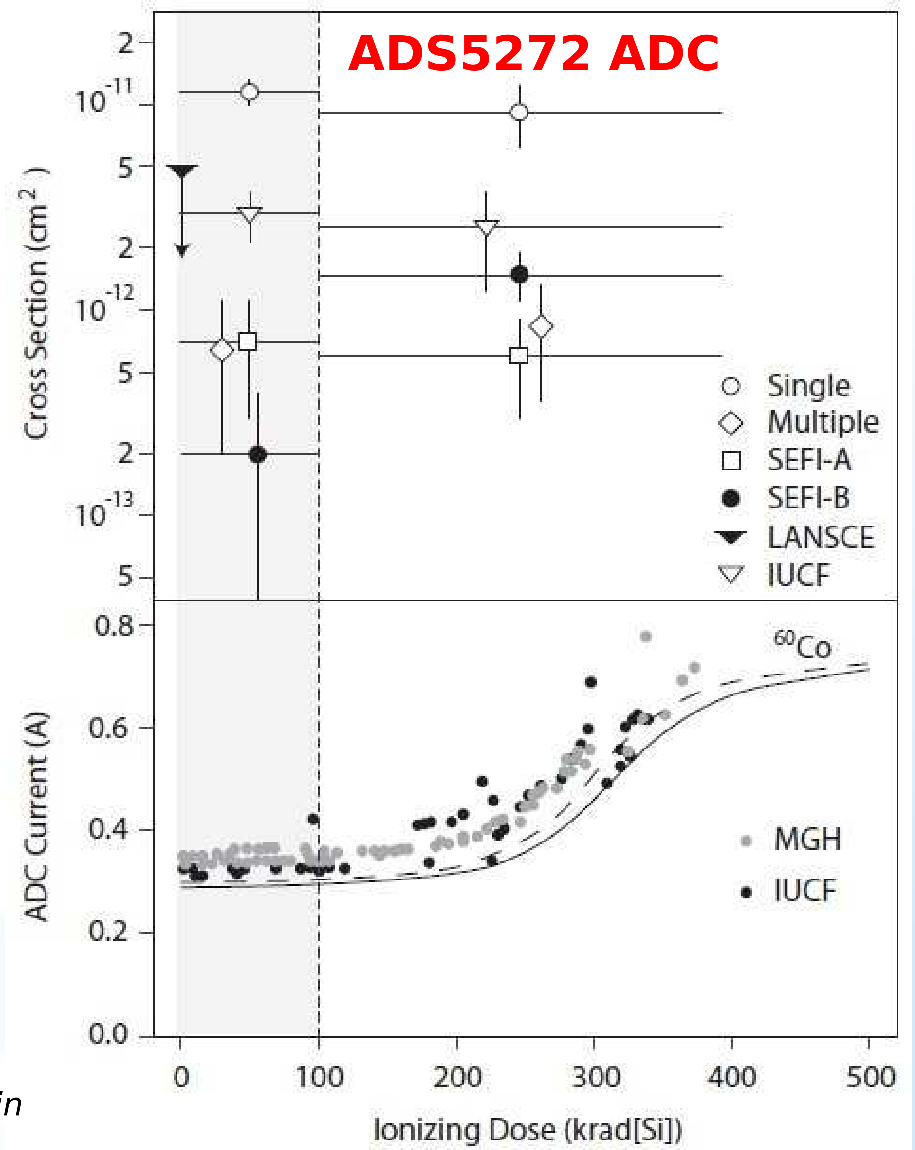

Irradiation of ADC and FPGA at LANSCE WNR

Component Evaluation & Qualification

- ***Small feature-size components are naturally radiation hard but sensitive to single-event upsets***

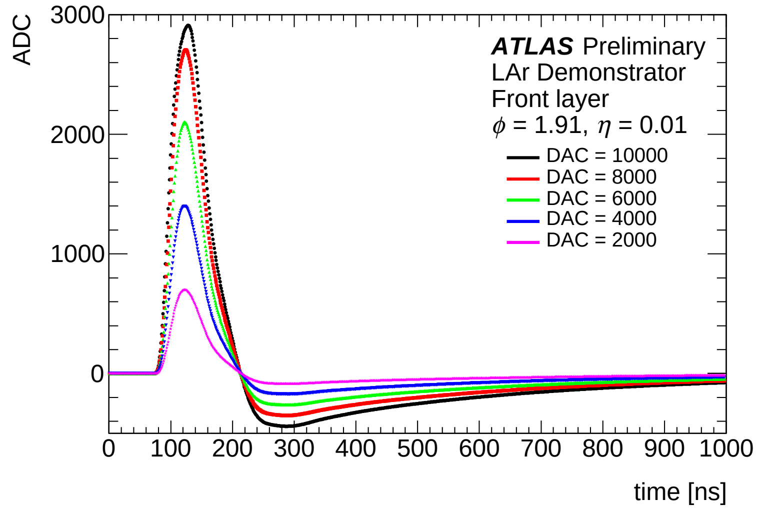
ADC	Dynamic Range [bit]	F [MHz]	Analog Input Span [V_{p-p}]	Channels per Chip	P_{total} per Channel [mW]	Feature Size (nm)	Vendor	TID [kRad (Si)]
AD9265-80	16	80	2	1	210	180	ADI	~220
AD9268-80	16	80	2	2	190	180	ADI	~160
AD9269-40	16	40	2	2	61	180	ADI	~120
AD9650-65	16	65	2.7	2	175	180	ADI	~170
AD9253-125	14	125	2	4	110	180	ADI	~105
LTC2204	16	40	2.25	1	480	350	Linear	~180
LTC2173-14	14	80	2	4	94	180	Linear	~105
LTC2193	16	80	2	2	125	180	Linear	~100
ADS4245	14	125	2	2	140	180	TI	~235
ADS6445	14	125	2	4	320	180	TI	~210
ADS5282	12	65	2	8	77	180	TI	~460
ADS5263	16	100	4	4	280	180	TI	~2100
ADS5294	14	80	2	8	77	180	TI	~1070
ADS5292	12	80	2	8	66	180	TI	~1060
ADS5272	12	65	2.03	8	125	180	TI	~8800
HMCAD1520	14	105	2	4	133	180	Hittite	~2300
HMCAD1102	12	80	2	8	59	180	Hittite	~1730

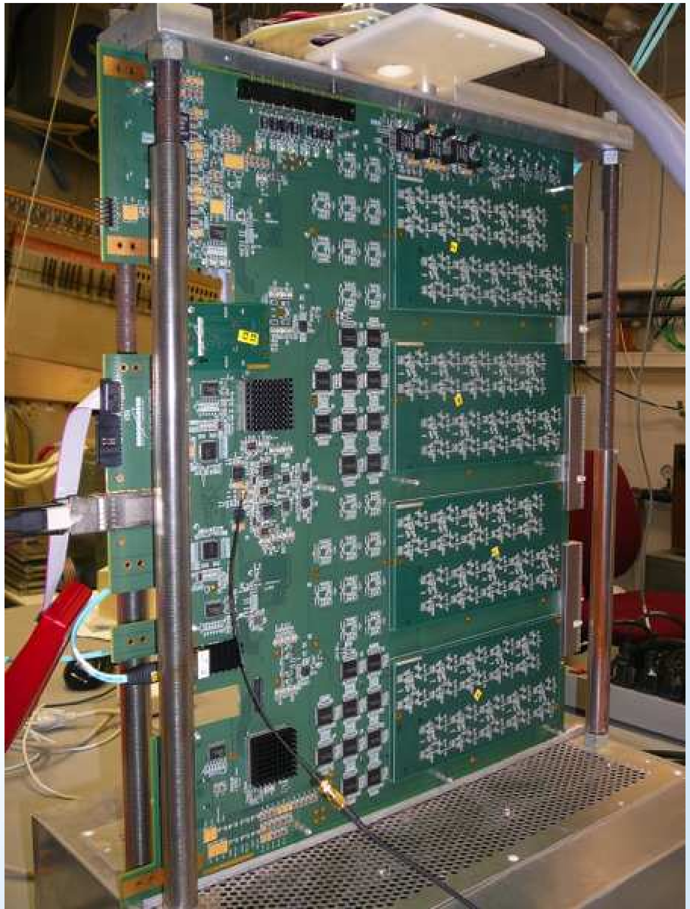
Results of total ionization dose (TID) tests for selected COTS ADCs [JINST 10 (2015) P08009]. TID is defined as failure to operate or a gain change larger than 5% — except for the last six ADCs that were still functional when the TID test was terminated.



High-Throughput Front-End Systems

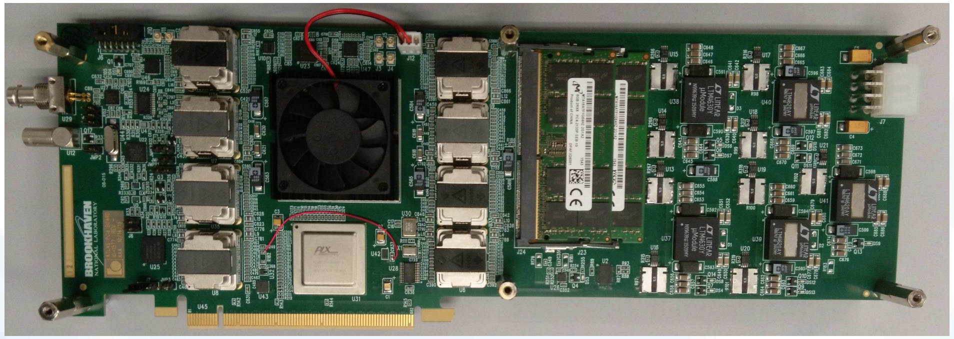
- ***BNL has developed front-end electronics based on our generic R&D experience including radiation qualification***
  - front-end board to digitize, process, and transmit calorimeter trigger signals
    - *320 signals digitized by 40 COTS ADCs (ADS5272) and processed by 4 FPGAs for transmission at 4.8 Gb/s over 40 fiber optical links*
    - *total transmission bandwidth is ~ 200 Gb/s*
    - *used as demonstrator for ATLAS Phase-I Liquid Argon Trigger Digitizer Board (LTDB)*
    - *installed in ATLAS in 2014 and successfully included during 2015 LHC run*

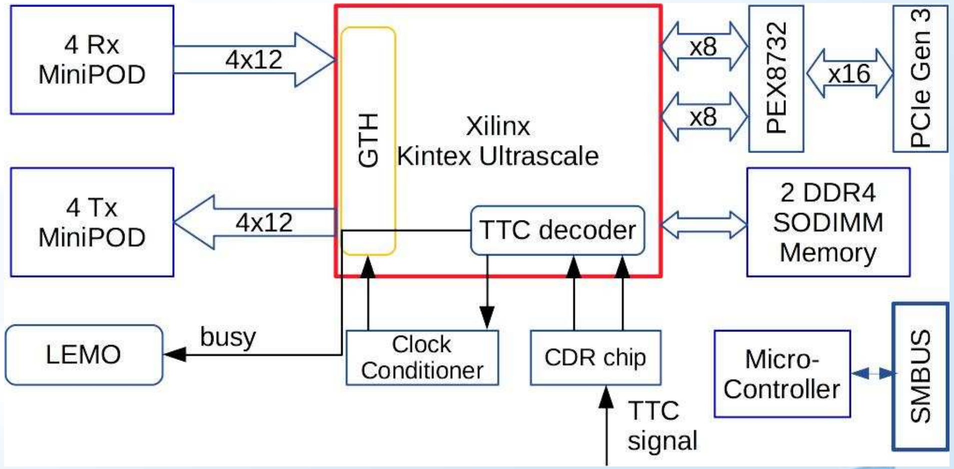




High-Throughput Front-End Data Transfer

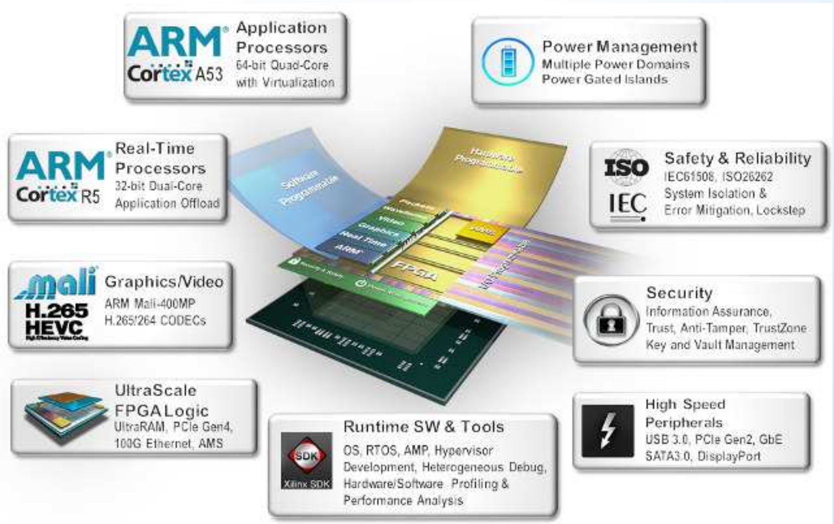
- ***Factorize front-end electronics from data handling***
  - front-ends operate in harsh radiation environment
  - off-detector data handling can utilize commercial networking solutions
- ***We've designed a generic PCIe board that receives and processes digital data from front-end electronics***
  - *Xilinx Kintex Ultrascale*
  - *48-channels Tx & 48-channels Rx in 8 miniPODs ⇒ ∼ 500 Gb/s throughput*
  - *versatile clock: 4.8, 5.12, 6.4, 8.0, 9.6, 10.24, 11.2, or 12.8 Gb/s*
  - *100G ethernet output*
  - *PCIe Gen3 ×16 lanes interface to host*
  - *micro-controller for FPGA configuration*
  - *clock and controls interface (TTC & busy)*
  - *up to 16 GB DDR4 memory*





High-Throughput Front-End Data Transfer

- ***Prototype based on Xilinx Ultrascale Kintex***
  - satisfies several roles in ATLAS Phase-I and HL-LHC Upgrades:
    - *Liquid Argon Calorimeter test stand*
    - *Tile Calorimeter test beam*
    - *Level 1 Calorimeter Trigger test stand*
    - *FELIX (Front-End LInk eXchange) prototype*
    - *TTC/clock distributor*
- ***Plan to switch to Xilinx Ultrascale+ Zynq MPSoC***
  - features:
    - *comparable PL capacity to Kintex Ultrascale*
    - *48 GTH → up to 72 GTH/GTY*
    - *quad-core ARM A53*
    - *dual-core ARM R5*
    - *MALI-400 GPU*
    - *4—5 PCIe Gen3×16/Gen 4×8*
    - *2—4 100G ethernet MAC*
    - *available in late 2016/early 2017*

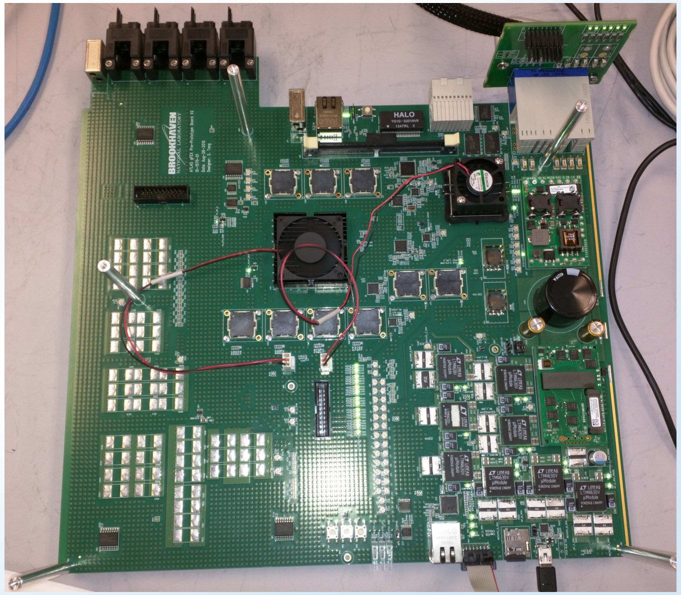


  - adaptable for experiments (e.g., DUNE) or test beams that benefit from an interface layer between front-end electronics and data handling

High-Throughput Trigger Electronics

- ***BNL is designing electronics to run fast trigger algorithms while also maximizing data throughput***
  - high-bandwidth fixed-latency trigger hardware typically features FPGAs with many transceivers to satisfy bandwidth, latency, & processing requirements

- ***Currently building module with 3 Xilinx Virtex-Ultrascale FPGAs and Zynq-7000 SoC***
  - up to 288 input optical fibers each running @ 11.2 Gb/s ⇒ 3.2 Tb/s
  - ATLAS Phase-I Level 1 Calorimeter Trigger global Feature Extractor (gFEX)
    - *entire calorimeter concentrated onto a single module*
    - *identifies large-scale hadronic objects & energy correlations at 40 MHz*
    - *conceived and built by BNL supported by university partners*



High-Throughput Trigger Electronics

- ***Increasing processing capacity and bandwidth yields additional flexibility and utility***
  - gFEX features 3 Xilinx Virtex-Ultrascale FPGAs and Zynq-7000 SoC
    - *up to 288 input optical fibers each running @ 11.2 Gb/s ⇒ 3.2 Tb/s*
  - proposed board has up to 4 Xilinx Virtex-Ultrascale+ FPGAs and Zynq Ultrascale+ MPSoC
    - *up to 500 input optical fibers each running @ ≥25 Gb/s ⇒ 15 Tb/s*
    - *connectors (PCIe Gen4 or similar) allowing commodity CPU & GPU cards to extend on-board computing capabilities provided by Zynq+*
  - ATLAS HL-LHC Upgrade options:
    - *High-Granularity Timing Detector Trigger Processor*
    - *Calorimeter and Muon Trigger Aggregater Modules*
    - *Global Event Trigger Processor*
    - *Region-of-Interest Distributor*
  - satisfies general requirements for low-deadtime calorimeter trigger envisioned in sPHENIX reference design

Partners & Connections

Microsemi
Texas Instruments
Altera
Czech Technical University in Prague
CERN
Hittite Microwave Products from Analog Devices
Linear Technology
Xilinx — All Programmable
Analog Devices
Weizmann Institute of Science
INFN Istituto Nazionale di Fisica Nucleare Sezione di Milano
Michigan State University
Argonne National Laboratory
Nikhef
Brookhaven National Laboratory
University of Oregon
Brigham Young University — Founded 1875 — Provo, Utah
The University of Chicago
SMU
Michigan

P5 Recommendation 28: *Strengthen university–national laboratory partnerships in instrumentation R&D through investment in instrumentation at universities. Encourage graduate programs with a focus on instrumentation education at HEP supported universities and laboratories, and fully exploit the unique capabilities and facilities offered at each.*

Resources & Budget

- ***KA25 support for trigger & DAQ generic R&D:***
  - Francesco Lanni (0.25 FTE including other KA25 activities)
  - Helio Takai (0.38 FTE)
- ***Budget***
  - existing R&D effort mainly supported by high-priority Energy Frontier projects
  - longer-term generic R&D needs continued KA25 support to remain successful

Conclusions

- ***Generic R&D at BNL focused on optimizing electronics for detector readout, data acquisition, and trigger***
  - in collaboration with university, laboratory, and industry partners
  - aligned with P5 recommendations for Energy & Intensity Frontier needs
- ***Impacts existing and new projects while generic development continues***
  - comprehensive program to evaluate radiation impact on COTS components
  - front-end electronics utilizing radiation-qualified COTS components
    - *successful demonstration platform for ATLAS Phase-I Liquid Argon electronics*
  - PCIe-based interface between front-end electronics & commodity networking
    - *potential clients include ATLAS Phase-I & HL-LHC Upgrades, DUNE, and test beams*
  - high-bandwidth real-time data processing for event selection
    - *potential clients include ATLAS Phase-I & HL-LHC Upgrades and sPHENIX*
- ***Small KA25 investment with large payout***
  - maximize physics output from accelerator-based experiments